

MAIKP114US

IT505US

ELECTRO-OPTICAL COMPONENT

REFERENCE TO RELATED APPLICATIONS

5

This application claims the benefit of the priority date of German application DE 103 03 676.8, filed on January 24, 2003, the contents of which are herein incorporated by reference in their entirety.

10

FIELD OF THE INVENTION

The invention relates to an electro-optical component and a method of employing such an element to transmit and receive millimeter or submillimeter waves.

BACKGROUND OF THE INVENTION

The term "millimeter waves" is understood hereinafter to mean electromagnetic waves whose wavelength (free space wavelength) lies in the millimeters range; correspondingly, the term "submillimeter waves" is understood to mean electromagnetic waves whose wavelength is less than one millimeter. The term "millimeter antenna" and "submillimeter antenna" is used hereinafter to mean antennas which can radiate and/or receive electromagnetic millimeter waves and submillimeter waves, respectively.

30

A component of this type is disclosed in the document "Monolithically integrated Yagi-Uda antenna for photonic emitter operating at 120 GHz" (A. Hirata, T. Furuta and T. Nagatsuma; Electronics Letters, 30 August 2001, Vol. 37, No. 18). This previously known component is an arrangement comprising a photodiode and a Yagi-Uda antenna connected to the photodiode. The photodiode, which is designed as a UTC (UTC:

uni-travelling-carrier photodiode), receives optical signals modulated with a signal frequency of 120 GHz and converts them into electrical signals. The electrical signals thus have an electrical frequency of
5 likewise 120 GHz and are radiated by the Yagi-Uda antenna connected to the UTC photodiode. In other words, the previously known component is an electro-optical transducer which converts optical signals with a high modulation frequency into
10 electromagnetic millimeter waves.

SUMMARY OF THE INVENTION

15 The invention is based on the object of specifying an electro-optical component which is particularly well suited to the generation of millimeter waves or submillimeter waves.

20 One advantage of the electro-optical component according to the invention can be seen in the fact that it has a particularly high efficiency in the conversion of optical signals into electromagnetic millimeter or submillimeter waves, because an electroabsorption
25 modulator is used for detecting the optical signals.

A further advantage of the electro-optical component according to the invention is that it has a double functionality, namely because the electroabsorption
30 modulator can also be operated in the opposite direction and can thus be used for generating modulated optical signals. This is because, in concrete terms, optical light signals with a modulation frequency which have been received by the millimeter or submillimeter
35 antenna connected to the electroabsorption modulator can be applied to the electro-optical component according to the invention.

For the already mentioned "opposite" direction in the operation of the electro-optical component - in other words for generating modulated optical light signals - an optical signal source such as a laser, for example, is employed. Therefore, in the context of one development of the electro-optical component, it is regarded as advantageous if the electro-optical component has or contains an optically active element. This is because, in such a case, a connection of a separate light source, in particular of a laser, to the electro-optical component can be dispensed with since the component then already contains such a light source itself.

It is possible to produce an electro-optical component with an electroabsorption modulator and an optically active element particularly simply and thus cost-effectively if the optically active element and the electroabsorption modulator are integrated in the same semiconductor substrate. This is because production steps can be saved in the case where the two components are integrated in the same semiconductor substrate.

For the generation of modulated optical light signals, it is regarded as advantageous if the optically active element is a laser, in particular a DFB (DFB: distributed feedback laser) or a DBR (DBR: distributed Bragg reflector) laser or an optical amplifier, in particular an SOA (SOA: semiconductor optical amplifier).

The electro-optical component can be formed in a particularly compact and thus space-saving manner if the millimeter or submillimeter antenna is arranged on the semiconductor substrate.

Instead of the millimeter or submillimeter antenna being integrated on the semiconductor substrate, it may alternatively be provided that the millimeter or submillimeter antenna is arranged on a circuit carrier and the semiconductor substrate is fixed on the circuit carrier.

For the targeted optimization of the electroabsorption modulator and of the optically active element, it is regarded as advantageous if the semiconductor substrate has at least two different active layers, of which one active layer is optimized for the optically active element and the further active layer is optimized for the electroabsorption modulator. The order of the layers is insignificant in this case, so that the active layer optimized for the optically active element may be arranged above the further layer optimized for the electroabsorption modulator, or conversely below said further layer.

QD (QD: quantum dot), MQD (MQD: multiple quantum dot), QW (QW: quantum well) and/or MQW (MQW: multiple quantum well) layers are suitable for the optimization of electroabsorption modulators and of optically active elements, so that it is regarded as advantageous if at least one of the two active layers is a QD layer, an MQD layer, a QW layer or an MQW layer.

Slotted antennas, in particular, are highly suitable for receiving and for generating millimeter or submillimeter waves, so that it is regarded as advantageous if a slotted antenna is used as the antenna in the electro-optical component.

The slotted antenna is advantageously a CPW-fed antenna fed by a coplanar electrical waveguide. In this case, the abbreviation CPW stands for "coplanar-waveguide-fed".

The millimeter or submillimeter antenna may, for example, also be a Yagi-Uda antenna or a "log-period" antenna.

5

Moreover, it is regarded as advantageous if the electromagnetic millimeter or submillimeter waves are focused in the antenna region; therefore, it is regarded as advantageous if a lens, in particular a silicon lens, for "refocusing" the electromagnetic waves is assigned to or arranged upstream of the millimeter or submillimeter antenna. The lens is advantageously hemispherically curved in order to achieve a particularly efficient focusing of the millimeter or submillimeter waves.

Moreover, it is regarded as advantageous if the semiconductor substrate belongs to the III/V material system; in particular, the semiconductor substrate may be, by way of example, an indium phosphite or a gallium arsenide material.

The invention is furthermore based on the object of specifying a method for generating millimeter and/or submillimeter waves which can be carried out particularly simply and efficiently.

With regard to the advantages of the method according to the invention and with regard to the advantages of the advantageous refinements of the method according to the invention, reference is made to the above explanations in connection with the electro-optical component according to the invention, since the advantages essentially correspond to one another.

35

BRIEF DESCRIPTION OF THE DRAWINGS

In order to elucidate the invention, Figures 1 to 4
show an exemplary embodiment of an electro-optical
5 component according to the invention.

Fig. 1 is a cross section diagram illustrating a
portion of an electro-optical element including a
semiconductor substrate according to one aspect of the
10 present invention;

Fig. 2 is a plan view of the semiconductor substrate of
Fig. 1 along with a waveguide coupled thereto according
to another aspect of the present invention;

15 Fig. 3 is a plan view of a printed circuit board upon
which various aspects of the invention may be
implemented; and

20 Fig. 4 is a plan view of the printed circuit board of
Fig. 3 along with a waveguide coupled thereto according
to yet another aspect of the present invention.

25 DETAILED DESCRIPTION OF THE INVENTION

Figure 1 illustrates a semiconductor substrate 1, which
is part of an electro-optical component 2. The
semiconductor substrate 1 may be n-doped, for example.
30 A DFB laser 5, an electroabsorption modulator 10 and an
optical amplifier 15 are integrated in the
semiconductor substrate 1.

The layer sequence of the semiconductor substrate 1 is
35 configured as follows: an active layer 20 optimized
specifically for the laser 5 is situated on the
semiconductor substrate 1. The active layer 20 may be,

by way of example, a QW layer, an MQW layer, a QD layer or an MQD layer.

5 A further active layer 25 specifically optimized for the electroabsorption modulator 10 is situated on the active layer 20. The order of the two active layers 20 and 25 is arbitrary, moreover; thus, the active layer 20 for the laser 5 may also be arranged above the further active layer 25 instead of below the latter.

10

Situated on the further layer 25 is a p-doped covering layer 30 provided with electrical contacts 35, 40 and 45 for making contact with the laser 5, the electroabsorption modulator 10 and the amplifier 15.

15

The covering layer 30 is segmented by trenches 50 and 55, as a result of which the regions for the laser 5, the electroabsorption modulator 10 and the amplifier 15 are demarcated from one another.

20

The DFB laser 5 has a grating structure 60 formed in the further active layer 25.

25 Figure 2 shows the semiconductor substrate 1 in accordance with Figure 1 in plan view. It reveals the grating structure 60 of the laser 5 and also the contacts 35, 40 and 45 with which the p-doped covering layer 30 is in each case contact-connected.

30 Furthermore, contact regions 70, 75 and 80 can be discerned, in which the p-doped covering layer 30 and also the two active layers 20 and 25 are removed - for example etched away. In said contact regions 70, 75 and 80, the n-doped semiconductor substrate 1, which is otherwise covered by the layers 20, 25 and 30, can be contact-connected from the front side or top side 85 of
35 the semiconductor substrate. The front side 85 and the rear side 90 of the semiconductor substrate are identified by their reference symbols in Figure 1.

Figure 2 furthermore illustrates an optical waveguide 95, for example a glass waveguide, which is connected to the semiconductor substrate 1 at the outer side 100 of the semiconductor substrate which faces the amplifier 15.

With this waveguide 95, it is possible to couple optical signals into the semiconductor substrate 1, which are converted into electrical signals by the electroabsorption modulator 10. In the other direction, it is possible to couple optical signals into the waveguide 95 from the semiconductor substrate 1, said signals being generated by the laser 5 and modulated by the electroabsorption modulator 10 in a manner dependent on electrical signals present at the electroabsorption modulator 10.

The light which is generated in the semiconductor substrate 1 and fed into the optical waveguide 95 is symbolized by an arrow bearing the reference symbol $P_{\text{opt,out}}$ in Figure 2; the light which is fed into the semiconductor substrate 1 is identified by an arrow bearing the reference symbol $P_{\text{opt,in}}$.

The laser 5 preferably has a length L_1 of between 50 μm and 500 μm . The electroabsorption modulator 10 preferably has a length of 50 μm to 300 μm ; the length L_3 of the electroabsorption modulator 10 is identified by the reference symbol L_2 in Figure 2. The length L_3 of the amplifier 15 is preferably 50 μm to 350 μm . The width b of the laser 5, of the electroabsorption modulator 10 and of the amplifier 15 is preferably 1 μm to 3 μm . The total width B of the semiconductor substrate 1 should preferably lie between 200 μm and 500 μm .

The wavelength λ_1 of the light $P_{\text{opt},\text{in}}$ radiated into the semiconductor substrate 1 may be identical to the wavelength λ_2 of the light $P_{\text{opt},\text{out}}$ generated by the laser 5; different wavelengths λ_1 and λ_2 are also possible instead.

Figure 3 reveals a lead frame 200, for example a printed circuit board on which two coplanar electrical conductors 205 and 210 form an electrical coplanar conductor 215, that is to say an electrical waveguide suitable for millimeter or submillimeter waves.

The two conductors 205 and 210 have a waveguide width w of approximately 10 μm to 50 μm and a distance A of between 20 μm and 80 μm

The two conductors 205 and 210 are connected by one of their line ends in each case to an antenna 220, which is formed from metal pads 225 and 230. The metal pads 225 and 230 have a width q of approximately 100 μm and a total length r (including distance A) of 500 μm to 2 mm.

The two conductors 205 and 210 are connected by their other line end to the contact 40 and the contact region 75 of the electroabsorption modulator 10, as is explained further below in connection with Figure 4. The electrical coplanar conductor 215 thus connects the antenna 220 and the electroabsorption modulator 10 to one another and is specifically dimensioned and designed for this in such a way that it is specifically suitable for the transmission of electrical millimeter and/or submillimeter waves and adapted in particular with regard to its characteristic impedance.

Figure 3 furthermore reveals connecting lines 235, 240, 245 and 250, which serve for making contact with the laser 5 and the amplifier 15. The way in which the electrical connecting lines 235, 240, 245 (width $s =$
5 10 μm - 50 μm) and 250 are connected in concrete terms is explained in connection with Figure 4.

The semiconductor substrate 1 in accordance with Figure 2 is additionally shown "rotated" in Figure 3 - that is to
10 say in a "phantom view" from below of the rear side 90 of the semiconductor substrate. This illustration is intended to indicate that the semiconductor substrate 1 is placed onto the lead frame 200 upside down and then soldered on. For the sake of clarity, only the contacts
15 and the contact regions are shown in this illustration.

Figure 4 shows the lead frame 200 and the semiconductor substrate 1 after the mounting thereof; the lead frame 200 and the semiconductor substrate 1 thus form the
20 electro-optical component 2.

It can be seen in Figure 4 that the contact region 70 for making contact with the "n-contact" of the laser 5 is connected to the connecting line 240. The "p-contact" of
25 the laser 5 is electrically driven via the contact 35 and thus via the connecting line 235.

The optical amplifier 15 is connected to the connecting line 245 via its p-contact 45; the connecting line 250 is
30 connected to the contact region 80 for making contact with the n-contact of the optical amplifier 15.

The p-contact 40 of the electroabsorption modulator 10 is connected to the conductor 210 of the electrical coplanar
35 conductor 215; the conductor 205 of the electrical coplanar conductor 215 is connected to the contact region 75 for making contact with the n-contact of the electroabsorption modulator 10.

The electrical component 2 in accordance with Figures 1 to 4 can be operated bi-directionally: on the one hand, with the electro-optical component 2, it is possible to convert optical light signals $P_{opt,in}$ into electrical waves $P_{electr.,out}$ in the millimeter and/or submillimeter range. On the other hand, it is possible - thus in the opposite direction - to generate a corresponding optical output signal $P_{opt,out}$ from electrical waves $P_{electr.,in}$ in the millimeter and/or submillimeter range.

10 This will now be explained briefly:

An optical input light signal $P_{opt,in}$ is absorbed by the electroabsorption modulator 10, as a result of which electron-hole pairs are generated, which bring about an electrical voltage at the connections 75 and 40 of the electroabsorption modulator 10. In the case of a light signal $P_{opt,in}$ modulated with a frequency of 100 GHz, for example, an electrical AC voltage thus forms at the connections 40 and 75 of the electroabsorption modulator 10, which voltage is likewise at 100 GHz and is transmitted via the electrical coplanar conductor 215 to the antenna 220 and radiated by the latter as millimeter or, in the case of higher data rates and thus higher frequencies, as submillimeter waves

25 $P_{electr,out}$.

In the opposite direction, the electro-optical component functions as follows: an electrical millimeter wave or submillimeter wave $P_{electr,in}$ is received by the antenna 220, whereupon a corresponding electrical signal or a corresponding electrical wave passes via the electrical coplanar conductor 215 to the electroabsorption modulator 10; this electrical signal drives the electroabsorption modulator 10 in such a way that the latter modulates its absorption behavior in accordance with the electrical signal. This then has the effect that the light generated by the laser 5 is modulated and modulated optical signals $P_{opt,out}$ are

generated, which are coupled into the optical waveguide
 95 from the semiconductor substrate 1. Although the
 invention has been illustrated and described with
 respect to one or more implementations, alterations
 5 and/or modifications may be made to the illustrated
 examples without departing from the spirit and scope of
 the appended claims. In addition, while a particular
 feature of the invention may have been disclosed with
 respect to only one of several implementations, such
 10 feature may be combined with one or more other features
 of the other implementations as may be desired and
 advantageous for any given or particular application.
 Furthermore, to the extent that the terms "including",
 "includes", "having", "has", "with", or variants
 15 thereof are used in either the detailed description and
 the claims, such terms are intended to be inclusive in
 a manner similar to the term "comprising".

List of reference symbols

| | | |
|----|------------|-----------------------------|
| 20 | 1 | Semiconductor substrate |
| | 2 | Electro-optical component |
| | 5 | DFB laser |
| | 10 | Electroabsorption modulator |
| 25 | 15 | Optical amplifier |
| | 20 | Active layer |
| | 25 | Further active layer |
| | 30 | p-doped covering layer |
| | 35, 40, 45 | Electrical contacts |
| 30 | 50, 55 | Trenches |
| | 60 | Grating structure |
| | 70, 75, 80 | Contact regions |
| | 85 | Front side |
| | 90 | Rear side |
| 35 | 95 | Optical waveguide |
| | 100 | Optical connection side |
| | 200 | Lead frame |
| | 205, 210 | Conductors |

MAIKP114US

IT505US

220

Antenna

225, 230

Metal pads

235, 240, 245, 250

Connecting line